A Review on the Comparison of EU Countries Based on Research and Development Efficiencies

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***Abstract*—**Nowadays, technological progress is one of the most important components of economic growth and the efficiency of R&D activities is particularly essential for countries. This study is an attempt to analyze the R&D efficiencies of EU countries. The indicators related to R&D efficiencies should be determined in advance in order to use DEA. For this reason a list of input and output indicators are derived from the literature review. Considering the data availability, a final list is given for the numerical analysis for future research.

***Keywords*—**Data envelopment analysis, economic growth, EU Countries, R&D efficiency.

I. Introduction

THE economic success has been gradually based on the effective utilization of intangible assets such as knowledge, skills and innovative potential as the crucial fact for competitive advantage. Since technological progress is one of the most important components of economic growth, the efficiency of R&D activities is particularly essential for countries nowadays, more than ever. This point motivates us to perform an analysis of R&D efficiencies of countries. European Union is selected as a region since the competitiveness is relatively higher in this area compared to the other regions in the world.

Efficiency can be simply defined as the ratio of output to input. More output per unit of input reflects relatively greater efficiency. If the greatest possible output per unit of input is achieved, a state of absolute or optimum efficiency has been achieved and it is not possible to become more efficient without new technology or other changes in the production process [1].

The efficiency definition is divided into three which are technical, economic and allocative efficiencies. Technical efficiency deals with the relation between inputs and outputs [2]. Economic efficiency deals with the same situation as technical efficiency but in terms of the price. When there are multiple inputs and the reason of the inefficiencies can be related to the mix of inputs used to produce the mix of outputs [1]; it is called allocative efficiency.

Non-parametric methods evaluate technical (technological) efficiency focusing on the level of inputs and outputs. Minimizing inputs at a given level of outputs or vice versa leads to being technically efficiency. The most commonly used technique in order to measure the technical efficiency is Data Envelopment Analysis (DEA) [3].

In parametric methods, economically efficiency is achieved by choosing a significant volume and structure of inputs and outputs in order to minimize cost or maximize profit. Economic efficiency requires both technical efficiency and efficient allocation. For technical efficiency one only needs input and output data while for economic efficiency price data is also needed. Among the parametric methods, the most widely used one is Stochastic Frontier Approach (SFA) [3].

In this study, technical efficiency of EU countries based on their R&D efficiencies is analyzed by DEA. The indicators related to R&D efficiencies should be determined in advance in order to use DEA. With this aim in mind, literature review is given in Section II and DEA is summarized in Section III. Section IV explains the application and Section V finalizes the paper.

II. Literature Review

Johansson et al examine the capacity of producing new knowledge with respect to patents granted in 18 industries in 11 European economies in between 1991-2005. The first aim of the study was to explore if they controlled some variables such as industry composition, institutional factors and R&D intensity, the observed differences in patent intensity would be the same or not. The second aim was to investigate whether certain countries have patenting advantages due to historical or other circumstances, while other countries have comparative advantages in other industries. For example; a country with an advantage in knowledge-intensive labor would specialize in more high-technology patent, on the other hand the one with an advantage in natural resource would specialize in more low-technology patents. This study shows that almost all industries are affected by country-specific conditions which lead to have different R&D efficiencies [4].

Thomas et al. investigate R&D efficiency in 22 countries, 20 of them members of the OECD, and the Russian Federation and China. The analysis is carried out using the Malmquist Productivity Index for the periods 2002-04 and 2004-06. This research has investigated the changes in R&D efficiency in consecutive time periods as distinct from the existing studies. With nations competing to increase and sustain the technological edge over others, it is imperative to identify the nations, which are currently leading the race for R&D efficiency and the reasons for their success. Results confirm the rapid advancement of China and the Republic of Korea, which is leading to reduced world shares of scientific publication and patents granted to residents of major scientific

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nations like the USA and the UK [5].

The essential condition to increase the R&D efficiency is being able to quantify its productivity. Previous studies in the same field usually have tried to evaluate R&D efficiency at the company or industry levels. The study of Lee and Park is an attempt to measure the R&D productivity in a wider manner compared to other studies. It is measured at the national level to provide R&D policy implications, especially for Asian countries. The twenty-seven countries are divided into for sub-groups depending on the output-specialized R&D efficiency: inventors, merchandisers, academicians and duds. Then, the distinctive features of the Asian countries regarding of R&D efficiency are identified [6].

Despite the fact that USA has the largest expenditure in R&D, its proportion in total patent grants among all the countries has been decreasing. This situation is valid for its proportion of World scientific publications, as well. A vast of research on R&D efficiency and technological innovation capability has considered the USA as a homogeneous entity and has not focused at the sub-national level. However, in the study of Thomas et al. where R&D efficiency of 50 US states and the District of Columbia is investigated, the R&D efficiency is estimated as the ratio of patents granted and scientific publications of R&D expenditures. The paper identifies the states in the US with the highest R&D efficiency and presents benchmarks which can be followed by policy interventions. This research highlights the significance of attending analyses of R&D efficiency using patent and publications at the sub-national level for informed policy making [7].

Roman highlights the common features of Romania and Bulgaria in terms of R&D activities and the existing differences in respect of knowledge based economy. The paper investigates R&D efficiency at the regional level for Romania and Bulgaria between 2003 and 2005, by using DEA analysis [8].

The literature review shows that DEA is the most widely technique in measuring R&D efficiency. Moreover, to the best of our knowledge, there has been no study in the literature, which compares all of the EU countries' R&D efficiencies. Therefore, this study is an attempt to fill this gap in the literature.

III. Data Envelopment Analysis (DEA)

If there are many inputs and outputs rather than one, the efficiency may be defined as a weighted sum of its outputs divided by a weighted sum of its inputs. This is the most common way for evaluation of efficiency of multi-input and multi-output cases. Formulation of the preference of these weights is constructed as a linear program by a method, which is called Data Envelopment Analysis (DEA). Within this technique, the efficiency values of each decision making unit (DMU) can be maximized compared to the other DMUs [9].

Data Envelopment Analysis (DEA) is a Linear Programming based non-parametric method of measuring the efficiency of a decision making unit (DMU), first introduced into the Operations Research (OR) literature by Charnes, Cooper and Rhodes [10]. The most important property that DEA distinguishes from the similar methods is being able to making evaluations with multiple inputs and outputs. DEA is a very powerful benchmarking technique, which benchmarks different DMUs and finds the relatively "best" DMU [1].

Initially DEA was only applicable for estimating technical efficiency in the public and non-profit sectors. Costs may not be available or trustworthy in this field which leads to miscalculations of cost minimizing or profit maximizing. Afterwards, it has been applied to various sectors to analyze the comparative/relative efficiency of homogeneous operating units such as banks, hospitals, supermarkets etc. [11].

As a result of DEA we obtain the effectiveness of each DMUs. For the inefficient DMUs, it provides scenarios on how to increase their efficiencies with respect to input/output ratios [9]. In other words DEA calculates the amount and type of cost and resource savings that can be achieved by making each inefficient unit as efficient as the most efficient - best practice – units. This allows the management to implement the suggestions derived from the results to achieve potential savings by utilizing the specific changes in the inefficient service units. In addition, DEA estimates the amount of additional service that an inefficient unit can provide without the need to use additional resources; which is a very desirable case for the managers. The efficiency analysis results in improving the productivity of the inefficient units, reducing operating costs and increasing profitability. These advantages make the DEA the most widely used technique in efficiency analysis, for both researchers and practitioners [1].

TABLE I
Mathematical Model Parameters and Variables

Symbol	Quantity
SU_j	service unit number j
J	number of service units being compared in the DEA analysis
θ	efficiency rating of the service unit being evaluated by DEA
y_{rj}	amount of output *r* used by service unit j
x_{ij}	amount of input *i* used by service unit j
I	number of inputs used by the Sus
R	number of outputs generated by the SUs
u_r	coefficient or weight assigned by DEA to output *r*
v_i	coefficient or weight assigned by DEA to input *i*

A. The Mathematical Formulations of DEA

The linear programming technique is used to find the set of coefficients (w's and v's) that will give the highest possible efficiency ratio of outputs to inputs for the service unit being evaluated. Table I provides the parameters and variables in a DEA mathematical model [1]. After solving the model (1)-(5), θ values will give the efficiency value of the service unit (SU), where 1 refers to the efficient ones and less than 1 refers to the relatively inefficient ones.

Objective Function:

$$\text{Maximize } \theta = \frac{u1y1o + u2y2o + \cdots + uryro}{v1x1o + v2x2o + \cdots + vmxmo} = \frac{\sum_{r=1}^{s} uryro}{\sum_{i=1}^{m} vixio} \qquad (1)$$

(Maximize the efficiency for service unit o.)

Subject to:

$$SU_1 \frac{u1y11+u2y21+\cdots+uryr1}{v1x11+v2x21+\cdots+vmxm1} = \frac{\sum_{r=1}^{s} uryr1}{\sum_{i=1}^{m} vixi2} \leq 1 \quad (2)$$

$$SU_2 \frac{u1y12+u2y22+\cdots+uryr2}{v1x12+v2x22+\cdots+vmxm2} = \frac{\sum_{r=1}^{s} uryr2}{\sum_{i=1}^{m} vixi2} \leq 1 \quad (3)$$

…

$$SU_j \frac{u1y1j+u2y2j+\cdots+uryrj}{v1x1j+v2x2j+\cdots+vmxmj} = \frac{\sum_{r=1}^{s} uryrj}{\sum_{i=1}^{m} vixij} \leq 1 \quad (4)$$

$$u_1, \ldots, u_s > 0 \text{ and } v_1, \ldots, v_m \geq 0 \quad (5)$$

IV. Application of DEA to R&D Efficiencies of EU Countries

In this study, the aim is to evaluate the Research and Development (R&D) efficiencies of the European Union (EU) countries; which are Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom. To the best of our knowledge, there has been no study in the literature that compares the efficiencies of all of the 27 EU countries with respect to their R&D activities. Moreover, there is a limited number of studies on R&D efficiency in the current literature independent from the countries analyzed. Therefore, this study is an attempt to fill the gap in the literature by evaluating the EU countries' efficiencies by using DEA, which is not only a measurement technique, but also a guide to increase the efficiencies for the countries which are not efficient.

TABLE II
R&D Efficiency Indicators

Indicator	The Studies That Use the Indicator	Input/Output	Data Availability (Yes/No)
Number of patents	[4]; [7]; [12]; [13]; [6]; [14]; [8]; [17]; [15]	Output	Yes
R&D expenditure	[4]; [7]; [6]; [7]; [16]; [14]; [8]; [17]; [15]	Input	Yes
Institutional quality	[18]; [19]; [4]	NA	No
The number of full-time researchers	[20]; [21]; [6]; [22]; [23]; [17]	Input	Yes
The number of scientific publications	[7]; [6]; [7]; [14]; [17]; [15]	Output	No
Number of MSc and PhD students hired	[13]	Input	Yes
Total educational expenditures(EDU)	[24]	Input	Yes
Gross Domestic Product (GDP)	[14]	Input	Yes
Total R&D expenditures conducted business enterprises (BERD), government (GOVERD) and higher education sector (HERD)	[22]	Input	Yes
Percentage of R&D performed by the government	[25]	NA	Yes
Employment in technology and knowledge-intensive sectors	[8]	Input	Yes
Number of international scientific and technical articles published or accepted in journals listed on SCI	[26]	Output	Yes
Number of patents registered in domestic patent offices	[26]	Output	Yes
Number of patents registered in foreign patent offices	[26]	Output	Yes
Number of students graduated with master's and doctoral degree and currently employed	[26]	Output	Yes
High-technology exports (% of manufactured exports)	[15]	Output	Yes

The indicators that are used in the literature to measure the R&D efficiency are given in Table II. In the last column, it is also given if the data is available or not. As can be seen from Table II, most of the studies that are related to R&D efficiency have been conducted in recent years; which show that the subject is relatively new to the literature. While the inputs are usually chosen as the R&D expenditure, number of MSc and PhD students hired and the number of researchers, the outputs is identified as the number of patents and the number of scientific publications. There are also other indicators which are institutional quality, innovation capacity, economic growth, per capita income and knowledge of English language. But they are not included in the table since they are not widely used and in order to be concise.

Since this study aims to analyze the EU countries, the data can be retrieved from Statistical Office of the European Communities (EUROSTAT). As a rule of thumb, DEA suggests that the number of DMUs (say *n*), should be defined as max {m*s, 3*(m + s)}, where *m* is then number of inputs and *s* is the number of outputs. Since the number of DMUs (i.e. number of EU countries) is equal to 27 in our study, the number of indicators should not be greater than 9. With this derivation in mind, among the indicators in the table, the input and output indicators are selected as follows – considering the data availability- :

Outputs: number of publications, number of patents registered by EPO (European Patent Office) and USPTO (United States Patent and Trademark Office);

Inputs: R&D expenditures conducted by business enterprises (BERD), government (GOVERD) and higher education sector (HERD), number of full time researchers, number of employed people that have master's and doctoral degree, employment in technology intensive companies.

V. Conclusion and Future Research

This study summarizes the studies on R&D efficiencies of countries and lists the commonly used indicators for the analysis. For further research, the DEA model will be run for the EU countries and the relative efficiencies will be compared using the specific inputs and outputs defined in the previous Section. We plan to make the analysis using the values for 2013 since 2014 values have not been published yet. For the inefficient countries, a guide which gives the optimal input-output range will be proposed. Both the model used in this study, the indicators listed and the numerical results that will be achieved in the future research will be useful for the EU countries for policy making in R&D activities.

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